3 mm spectrometer complex on the base of SIS receiver and acousto-optical spectrum analyzer

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Introduction

Within the framework of the long-term program of studies of dense interstellar gas in molecular lines on the radio telescope RT-22 of the Crimean Astrophysical Observatory in May-July 1998 the observing session with the modernized instrument complex for spectral measurements at 3 mm wavelengths was performed. Receiver with the mixer based on a superconductor-insulator-superconductor (SIS) structure, cooled by 4.5 K closed-cycle cooling system was used in the complex. SIS-structure was design and made in Institute of Radio Engineering and Electronics (Shitov et al., 1992). First measurements with this SIS receiver on the RT-22 were made in 1995 (Zinchenko et al., 1997). DSB noise temperature of the receiver in the range 85–110 GGz was 80–150 K. During the current session an acousto-optical spectrum analyzer (AOS) was used, instead of the filterbank spectrum analyzer used earlier. AOS was designed and made in the St.-Petersburg Technical University (Esepkina et al. 1994). A broad total band of the AOS and a good spectral resolution (Table 2) have allowed to apply it to investigations of lines in molecular clouds with high-velocity flows and to observe simultaneously several close molecular lines in one object. Also in 1995–1998 the receiver was modernized. The system of automation of tuning of the SIS mixer was developed which was tested during the last observations, the reliability of a system of the helium level temperature stabiliser is increased, that has appeared important in climatic conditions of Crimea.

SIS receiver

The structure of the receiver is presented in Fig. 1. DSB noise temperature of the receiver in the range 85–110 GHz was in limits 80–150 K. Potentially possible values of noise temperature for SIS-receivers of a similar configuration for a construction cooled immediately by liquid helium in a transport Dewar, was about 40 K. The difference is caused by the several reasons. The principal one is a worse noise temperature of the first intermediate frequency amplifier (IFA) and mismatch between the SIS-structure and 50 Ohm IF impedance. The integrated noise temperature of IFA with an isolator on an input in a band 1.3–1.6 GHz at different amplifier physical temperatures are shown in Table 1.

The noise performance of the amplifier was measured by the method of two loads, at room temperature (295 K) and at 15 K, the test loads $T_{\rm hot} \approx 295$ K (room temperature) and $T_{\rm cold} \approx 80$ K (temperature of liquid nitrogen) were used. At a helium level of temperatures (4.5 K) SIS-structure was used as a noise generator. On a section of a normal resistance, its shot noise is determined by Eq. (1):

$$T_{\rm n} = 5.76 V_{\rm mV} \quad (K), \tag{1}$$

where V is the bias voltage on SIS-junction.

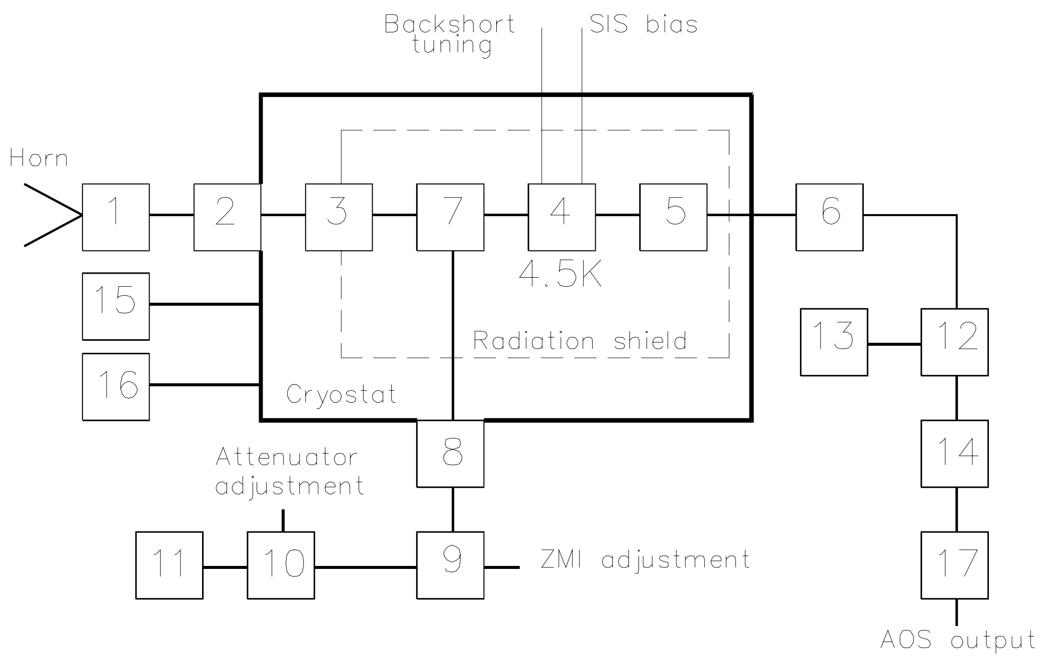

Figure 1: The block diagram of the receiver: (1) waveguide taper-axis rotation; (2) sealed signal window; (3) thermodecoupling junction; (4) SIS mixer; (5) cooled IF preamplifier; (6) additional amplifier of the first IF stage; (7) directional coupler with crossed waveguides; (8) hermetically sealed local-oscillator window; (9) Zender-Mach interferometer (ZMI); (10) adjustable attenuator; (11) phase-locked local oscillator; (14) second IF amplifier; (15) microcryogenic system; (16) vacuum pump; (17) AOS

Table 1:

Amplifier physical temperature	295 K	15 K	4.5 K
Amplifier noise temperature	39 K	6 K	16 K (with allowance for mismatches with the mixer and losses in a connective cable)

Two references at different voltages on SIS junction simulate hot and cold loads. Such approach allows to measure noise temperature of the whole intermediate frequency circuit in the working receiver including mismatches of the structure with 50-Ohm IF circuit, and losses of a connective circuit between mixer element and IFA. Other possible reasons of increased noise temperature can be a non-optimum choice of the SIS structure itself, higher operating temperature (4.5 K instead of 4.2 K), increased level of breakthrough and vibration accompanying work of MCS.

In laboratory conditions the receiver was tested in DSB regime. During observations on the telescope, at some frequencies an asymmetrical reception was observed, when the difference between the signal and image bands was of the order of 10 dB. That is explained probably by complicated amplitude-frequency characteristics (AFC) of a circuit consisting of an receiving horn, vacuum window, thermo-isolated stainless waveguide, direct coupler, SIS structure and tuning backshort. It confirms one effect: at visual monitoring on the oscilloscope spectrum analyzer output at sequential reading of all channels, at defined values of biasing voltage SIS structure, heterodyne level and backshort position, it was visible, that on these frequencies the response of a signal on intermediate frequency had a resonance character. The laboratory experiment on study such behaviour of the receiver is now prepared. The generator with a grid of frequencies in a range of 3 mm is developed for this purpose which will be used by us a source of standard signals.

The IF circuit was developed with allowance for possibilities of a work of a receiving complex both with the old filterbank spectrum analyzer and with AOS. For this purpose the new broadband converter on the second intermediate frequency was made. On the second IF the converter band at the 3 dB level ranges from 50 MHz to 280 MHz with ripples inside a band less than 1.5dB.

Spectrum analyzers

The quality of spectral radio astronomical measurements, alongside with the sensitivity of a receiving complex and spatial resolution, is determined by spectrum analyzer. Different tasks impose specific requirements to its performance. A high spectral resolution is needed for studies of a fine structure of lines, especially for observations of cold interstellar molecular clouds (a resolution ≤ 20 kHz is required). At the same time a broad band of the analysis is needed for observations of objects with high-velocity flows. The highest flow velocity is ~ 100 km/s, which implies a bandwidth of ≥ 60 MHz at $\lambda \sim 3$ mm. Previously we used a 120 channel filterbank as a spectrum analyzer. Now two other types of spectrum analyzers are considered: a digital Fourier transform (FFT) spectrometer and AOS. In 1998 observing session we used AOS developed at the St.-Petersburg Technical University. The FFT analyzer is developed at IAP RAS. The analyzer characteristics are presented in Table 2.

Table 2. Performance of spectrum analyzers

Type	*Bandwidth* MHz	*Resolution* kHz	*Band* MHz	*Dynamic range* dB
Filterbank	12	100	236–248	30
AOS	75	152	113–188	25
FFT	20	20	0–20	30

Cryogenic complex

The mixer and first IF amplifier are cooled to 4.5 K by closed cycle MCS. Cooling capacity of 4.5 K stage is about 1 W. The system of temperature stabilization provided long-term stability of 0.15 K during 24 hours at variations of ambient temperature from 10 C up to 35 C. Such temperature stability is necessary for normal operation of the mixer, since the bias voltage strongly depends on the temperature of SIS structure. The working ability at hot temperature is very important for Crimea climate. Problems have raised from two reasons: the main one is the radiation load on the cooling system which increases as T^4_{amb}, the second reason is hard operating conditions for one of the compressors on the telescope. These problems can be solved by using of cryostat with little area of cooling elements (this is radiation shield and receiver blocks) and by using additional cooling system (maybe water pump) for compressor.

Conclusion

Modernized spectrometer complex with AOS has demonstrated good efficiency for radio astronomical 3 mm observations (Fig. 2). AOS bandwidth is significantly broader than in the filterbank spectrum analyzer used earlier. This gave us ability to research objects with broad spectral lines, including objects with high-velocity flows and lines from external galaxies. A further essential improvement of receiving complex is possible. It includes decreasing of noise temperature of the receiver, determination of the reasons of asymmetrical receiving at observations on some frequencies and avoidance of similar effect. Concerning the spectrum analyzer a combination of AOS with FFT might be fruitful. For better work of the cooling system a new cryostat and compressor cooling system can be used.

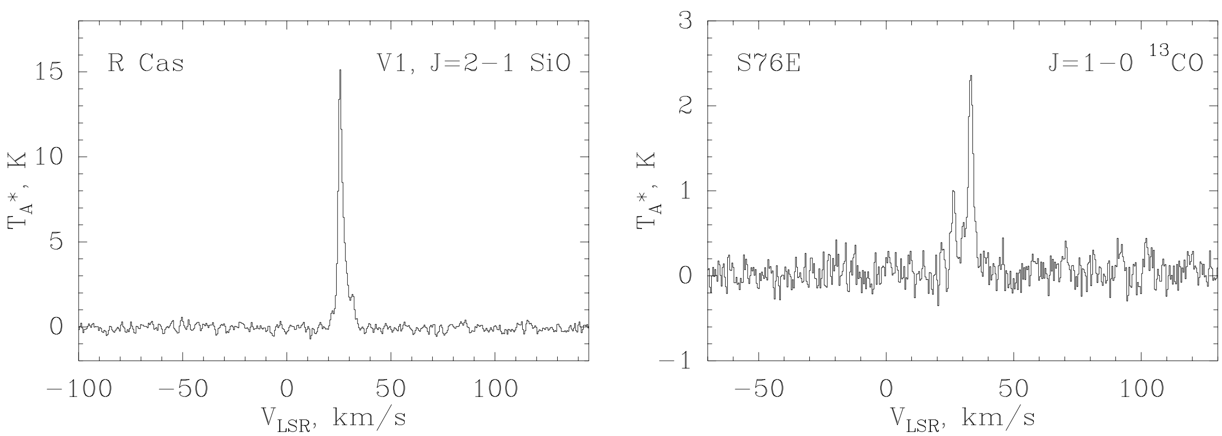

Figure 2: Examples of the spectra measured at RT-22 CrAO in 1998

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